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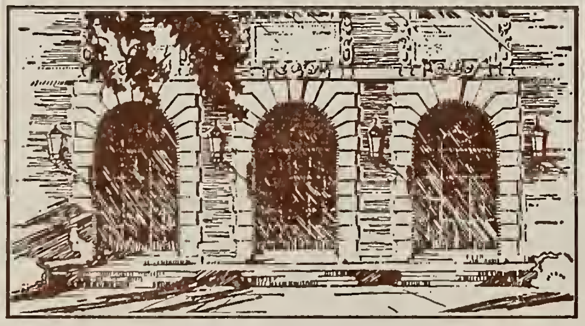

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LASCOT:
A LARGE SCREEN COLOR TELEVISION SYSTEM

by

Mehernosh Nariman Cooper

June, 1973

DEPARTMENT OF COMPUTER SCIENCE
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LASCOT:

A LARGE SCREEN COLOR TELEVISION SYSTEM

BY

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THESIS

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LASCOT: A LARGE SCREEN COLOR TELEVISION SYSTEM

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The Large Screen Color Television System as proposed by Dr. W. J. Poppelbaum is a laser projection display which produces a color television picture on a large screen place some distance away. Constructing an economical display system was the chief objective. Toward this end relatively inexpensive electro-mechanical mirrors are used for beam deflection. These mirrors are synchronized with the composite video.

LASCOT uses a mixed gas (Argon-Krypton) laser as its light source. The blue, green and red colored beams are intensity modulated by electro-optic light modulators (EOLMs). These EOLMs are driven by the blue, green and red picture signals derived from a standard commercial television receiver. These modulated beams are combined by means of dichroic mirrors. This composite beam has a color and hue which depends on the signals at the EOLMs. The composite beam is then deflected horizontally and vertically by means of the horizontal and vertical deflection mirrors. These deflection mirrors are synchronized to their respective synchronization signals which are derived from the television receiver. The picture is projected on a 3 foot by 4 foot high-gain screen. The overall resolution of the picture is in excess of 120 spots horizontally and 100 spots vertically.

ACKNOWLEDGMENT

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1. INTRODUCTION

1.1 Laser Displays

Laser displays have received considerable attention in the last few years. This attention has resulted from the developments in laser technology which have made high wattage Argon and Argon-Krypton lasers available. All of these recent displays have been directed toward making a large screen display with an acceptable resolution. It is noteworthy that these various attempts have differred significantly from each other only in the components used to perform the operations of modulation and deflection. Otherwise, the basic idea has remained essentially the same.

Constructing a large screen CRT poses a significant number of mechanical, as well as electrical, problems. It was thought to replace the electron beam of the CRT by a laser beam in air, thereby eliminating the need for vacuum and low efficiency phosphers. The CRT, of course, performs the modulation and deflection of the electron beam very conveniently. Thus, a means for modulation and deflection of a laser beam were investigated by various researchers.(1,2,3) It is in performing this modulation and deflection of the laser beam that the various approaches differ significantly.

Let us examine the salient features of two of the more successful ventures before explaining the approach taken in LASCOT.

Zenith Laser Television:(4)--This is basically a monochrome television system using a He Ne laser as its light source. In this television system, acousto-optic Bragg cells are used to perform modulation and deflection of the laser beam. The modulation is accomplished by varying the amplitude of the acoustic wavefronts in the cell as the laser beam enters and leaves the acoustic cell at the "Bragg angle." The frequency of the traveling acoustic wave is held constant and thus the Bragg angle stays constant. The changes in amplitude of the acoustic wavefronts cause a change in the laser power diffracted from the laser beam.

The horizontal deflection is accomplished by another acoustic cell in which the Bragg angle is varied in accordance with the deflection needed. The Bragg angle is varied by varying the frequency of the traveling acoustic wave in the cell. For maximum intensity in the diffracted beam the Bragg diffraction requires that the acoustic wavefront by symmetrical with respect to the incident and diffracted light beam. Thus, as the Bragg angle is varied, the acoustic wavefront must rotate also. This is accomplished by the ingenious use of a phased array of transducers whose combined wavefront rotates as the frequency (Bragg angle) changes. It is claimed that this phased array scheme of transducers improves the horizontal resolution from 73 spots to 200 spots. It must be observed that acousto-optic deflectors have a maximum efficiency at only one wavelength of light (the wavelength at which the Bragg condition holds). Therefore, acousto-optic cells are unsuitable for tri-color operation.

The vertical deflection is accomplished by a galvanometer type mirror.

The General Telephone Experimental Color Television:(5)--This system uses both an argon and a krypton laser as light sources to obtain the three required "primary colors." The system uses three compensated electro-optic light modulators for intensity modulation of the three colored beams.

The horizontal deflection is accomplished by a rotating polygonal mirror which is synchronized to the composite video signal by a phase locked loop. Rotating polygonal mirrors meeting television display requirements of resolution, deflection angle, retrace period, and scan frequency must be of large size and rotate at speeds which are quite unsafe. A "dual polarization" scheme was used which reduced the size of the polygonal mirror thus reducing the kinetic energy of the mirror.

The vertical deflection is accomplished by a motor driven vibrating mirror. The system has a resolution of 500 lines.

In their later version of this display a mixed gas laser was used as the light source and the three electro-optic light modulators have been replaced by one multi-color modulator which performs the overall function of three modulators.

1.2 Other Large Screen Displays

General Electric Color Television Display:(6)--The most important component of this system is a light valve. A light valve consists of a light source, a set of input slots, a schlieren lens, a fluid surface, output bars, a projection lens and an electron gun. Each bar grating (input and output) is placed at the foci of the schlieren lens, and positioned such that each bar within a grating is imaged upon an opening of the second grating. Therefore, the light rays entering through the input grating will be blocked by the output grating. When the electron gun deposites a charge on the oil film, the electrostatic force deforms the oil film, thus causing the light to diffract and escape through the output grating. This diffracted light energy is collected by the projection lens and is projected on a distant screen. The diffracted light is proportional to the deformation of the oil film and is thus a function of the charge deposited by the electron gun. If a modulated electron beam traces a picture on the oil film, each element of this picture acts as a diffraction element of varying intensity and thus a picture is produced on the screen. The charge decays through the oil film to a conductive coating within one frame time, thus providing proper storage and persistence. The oil film uniformity is maintained by an oil reservoir and a mechanically operated spreading system. A monochrome TV picture can be projected on the screen in this way.

To develope a color picture with this system, it is necessary to write a multiplicity of grooves or a diffraction grating within each picture element which determines the color and the brightness. Three differentially pitched diffraction gratings are written simultaneously (one for each primary color). In order to minimize the interaction between these gratings, the green grating is at right angles to the other two (i.e. blue and red) gratings. The green picture is written by modulation of a spot-defocusing voltage controlled by the green video information. This is accomplished by a VHF wobbulation voltage applied to the vertical deflection plates. The red and blue picture grating is formed by velocity modulating the spot with a high frequency voltage applied to the horizontal deflection plates. The pitch (frequency) of the red grating is chosen such that the red light from the developed spectrum is passed and the blue light is blocked. Another frequency is chosen for blue such that the blue light will be passed through the output slots and the red light will be blocked. Thus, there is a way of writing a full color picture by applying the three color video signals to the three modulators whose outputs are connected to the appropriate deflection plates. Thus a color picture is projected on the screen by the projection lens.

The system uses a 500 watt Xenon lamp as its light source and has a resolution in excess of 250 lines. The light valve has an average life of 50 to 100 hours.

2. LASCOT SYSTEM

LASCOT is a display system which projects a color television picture on a large screen. The most unique feature of the system is its use of mechanically vibrating mirrors for the deflection of the laser beam. The mirrors are synchronized with the video waveforms to form a complete picture. The size of the picture is limited only by the output power of the Ar-Kr laser which serves the function of a three colored light source. As the picture is made larger its brightness decreases according to the inverse square law.

Figure 1 shows a schematic diagram of the LASCOT system. A commercial color television receiver (Zenith Model C-3520) is used for receiving the desired TV broadcast. The video (luminance or Y signal) and chroma (R-Y, G-Y and B-Y) signals are tapped from the video amplifier and chroma demodulater stages of the television receiver. These signals are processed and amplified to form Red, Green and Blue intensity signals which are then used to drive the electro-optic light modulators (EOLMs) corresponding to that color. The television receiver also provides the horizontal and vertical synchronizing signals. These signals are used to generate the deflection waveforms.

A Spectra Physics Model 164 Mixed gas (Argon-Krypton) Laser is used as a light source. It has a power output of 250 m watts in the Red (6471 A°), Green (5145 A°) and Blue (4880 A°) along with other wavelengths which are not used. The polarization of the laser beam is in a vertical plane. To reduce reflection losses at the surfaces of prisms, the polarization of the beam is rotated by 90° so that the beam is horizontally polarized. This rotation is done by a corner reflector as shown in Figure 1. The beam is split up into its various color components by

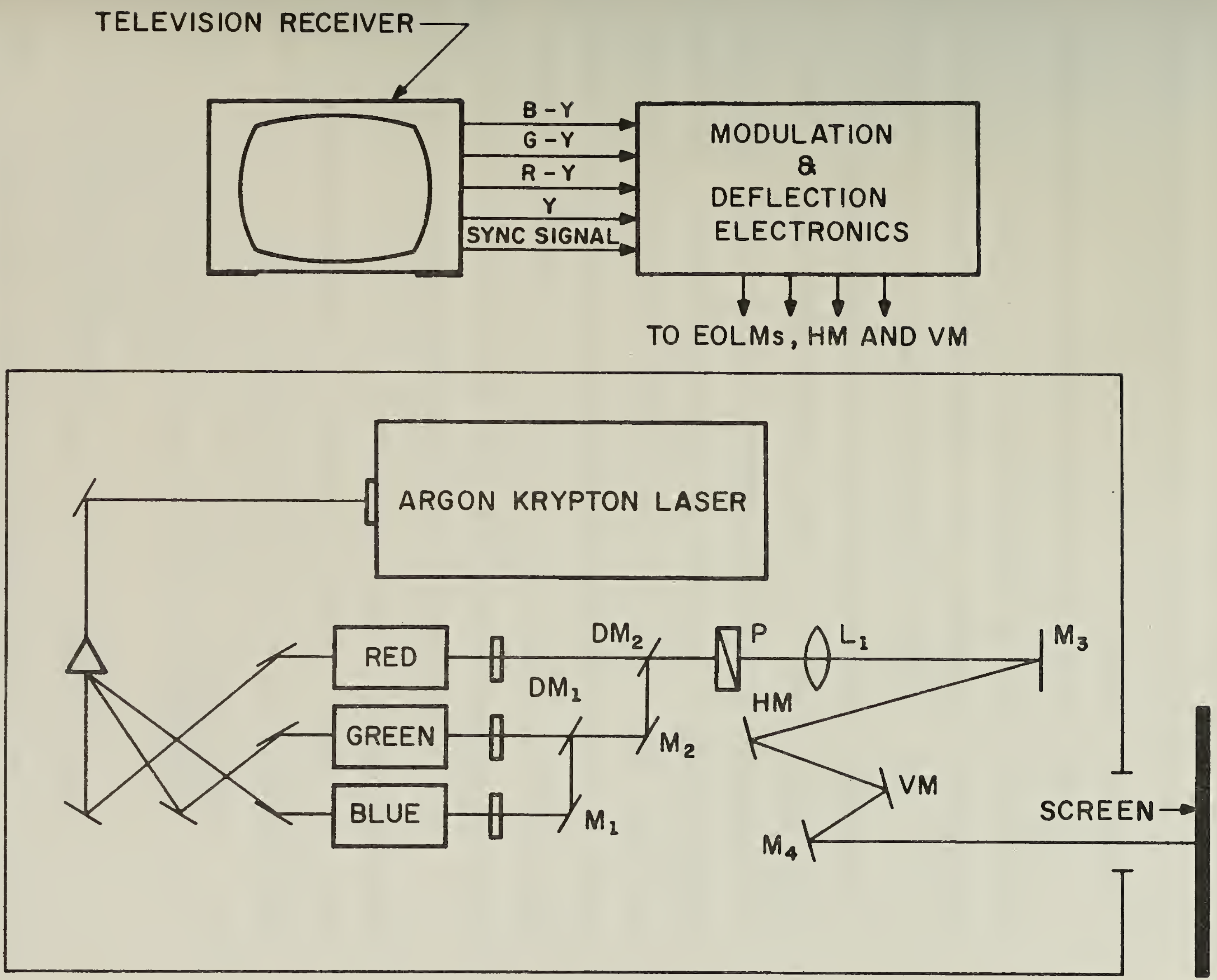


Figure 1. LASCOT Schematic

means to two prisms. The angle of incidence of the beam is kept such that the sum of the reflection losses at the two surfaces of each prism is minimum. Front-surface mirrors are used to direct the various colored beams to their respective EOLMs. The angle of incidence of the beam with the EOLM face is normal.

The EOLMs are driven by the Red, Green and Blue signals respectively. These signals, as discussed earlier, are obtained from the television receiver. These signals are buffered, amplified, and then fed to the EOLM driver circuit. A phase modulated beam leaves the EOLM in which the difference in phase (between the x and y components vectors) is directly proportional to the voltage applied to the EOLM.

The outgoing beams are combined to form one beam by two dichroic mirrors DM1 and DM2. M1 and M2 are front-surface mirrors. The dichroic mirror DM1 refelcts the blue beam and transmits the green beam. With proper alignment the blue and the green beams can be merged. The dichroic mirror DM2 reflects blue and green where as it transmits red. Again, with proper alignment, the outgoing beam from DM2 has the red beam merged with the blue and the green beams. The $\frac{\lambda}{4}$ plates are kept in the paths of the beams for reasons to be explained later. The combined beam passes through the polarizer P which performs the function of converting the phase modulated beam into an intensity modulated beam, such that$^{(8)}$.

$$\frac{I_{TRANSMITTED}}{I_{INCIDENT}} = \mathrm{Sin}^2 \frac{\Gamma}{2}$$

Γ = phase retardation between the x and y components.

$$= \mathrm{Sin}^2\left(\frac{\pi}{2} \frac{V}{V_{1/2}}\right)$$

V = applied voltage to EOLM

Where $V_{1/2}$ is half wave retardation voltage and is the value of V for which $\Gamma(\lambda) = \pi$. For the EOLM used (Crystalab Model EOM-3050A), the $V_{1/2}$

is 350 volts for λ = 4880 A and 365 volts for λ = 5145 A. The outgoing beam from the polarizer is now intensity modulated; the intensity of various color components being proportional to the Red, Green and Blue signals originally obtained from the television receiver.

The intensity modulated beam is now converged by means of a biconvex achromatic lens L_1. The focal length of L_1 is very large (800 mm) and is such that the beam diameter is sufficiently small to be contained by the horizontal deflection mirror (HM). This converging of the beam by L_1 is necessary because the horizontal deflection mirror is much smaller than the beam diameter and without converging much of the light would be wasted. The horizontal deflection mirror is CEC Model 7-366 which is a galvanometer-type deflection mirror. It has a flat frequency response upto 25 KHz. The mirror is driven by a 7.875 KHz triangular waveform which is synchronized to the horizontal oscillater of the television receiver. Since the mirror vibrates at half the horizontal deflection frequency of the television, every alternate line is blanked out. The mirror has a deflection angle of 3° peak-to-peak. The beam falls on the vertical deflection mirror (VM) after being reflected from HM.

The vertical deflection mirror has a 1/2" square surface and has a frequency response which is flat up to 1500 Hz. This mirror is driven by a sawtooth scanning frequency (30 Hz), all of the higher harmonics of the sawtooth are effective thus giving good vertical linearity. The vertical scanning waveform is synchronized to the vertical oscillator of the television receiver.

The beam, after being reflected by the front surface mirror M_4, falls on the screen. When the optics are aligned properly, a white spot appears at the center of the screen with the horizontal and vertical deflection mirrors de-energized. When the mirrors are energized, a white raster appears on the screen. The problem of dynamic convergence is absent here. That is, if the beam is statically coincident (white), it will stay coincident when deflected. When the modulators are turned on, a picture is seen on the screen.

A high gain screen is used to enhance the brightness of the picture within a narrow angle of viewing.

LASCOT is a relatively inexpensive system which makes very efficient use of vibrating mirrors for deflection purposes. The components used in this system are readily available and all of them have a relatively long life. The system does not use any intricate component such as a light value.

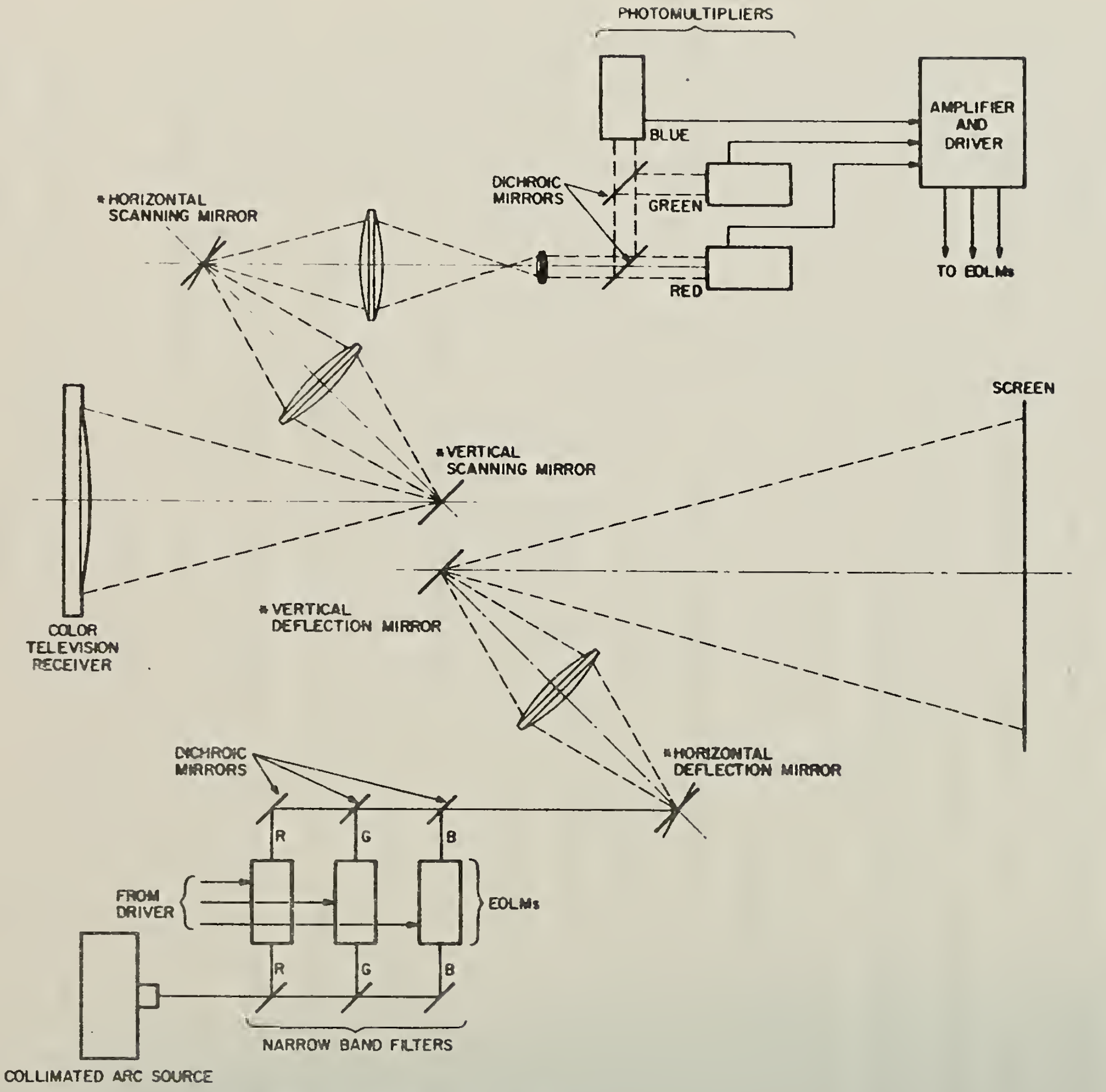
3. EARLIER ATTEMPTS

It should be noted that the final LASCOT system was arrived at after an unseccessful earlier attempt. In this chapter we shall briefly review that system and will discuss the factors that contributed to its failure. The block diagram of the system is shown in the Figure 2. The system essentially consists of a) a Scanning System, b) a Modulation System and c) a Deflection System.

3.1 The Scanner

In this system, the scanner generates its own synchronized video signal (which is not synchronized to the television receiver). A standard color television receiver is scanned by two vibrating mirrors (horizontal and vertical) and the image is picked up by the photomultiplier assembly. The details of the photomultiplier assembly are shown in Figure 3. It consists of photomultipliers partitioned by the dichroic mirrors DM_1 and DM_2. The dichroic mirror DM_1 transmits red and reflects blue and green where DM_2 transmits green and reflects blue and red. Thus, with this arrangement the photomultipliers PM_1, PM_2 and PM_3 respond to predominantly red, blue and green colors.

The light is allowed into the photomultiplier assembly through a very small aperture A_1. It is the diameter of A_1 and the magnification optics of the scanner that determine the resolution of the scanner. The smaller the diameter of A_1, the greater the details of the picture that can be detected but the lower the flux of light that reaches the photomultipliers. This causes a decrease in the signal-to-noise ratio at the output of the photomultipliers. The incoming beam of light (the one picked up from the television receiver screen) is split up into three



* VERTICAL AND HORIZONTAL MIRRORS ARE SYNCHRONIZED

Figure 2. LASCOT--Earlier Attempt

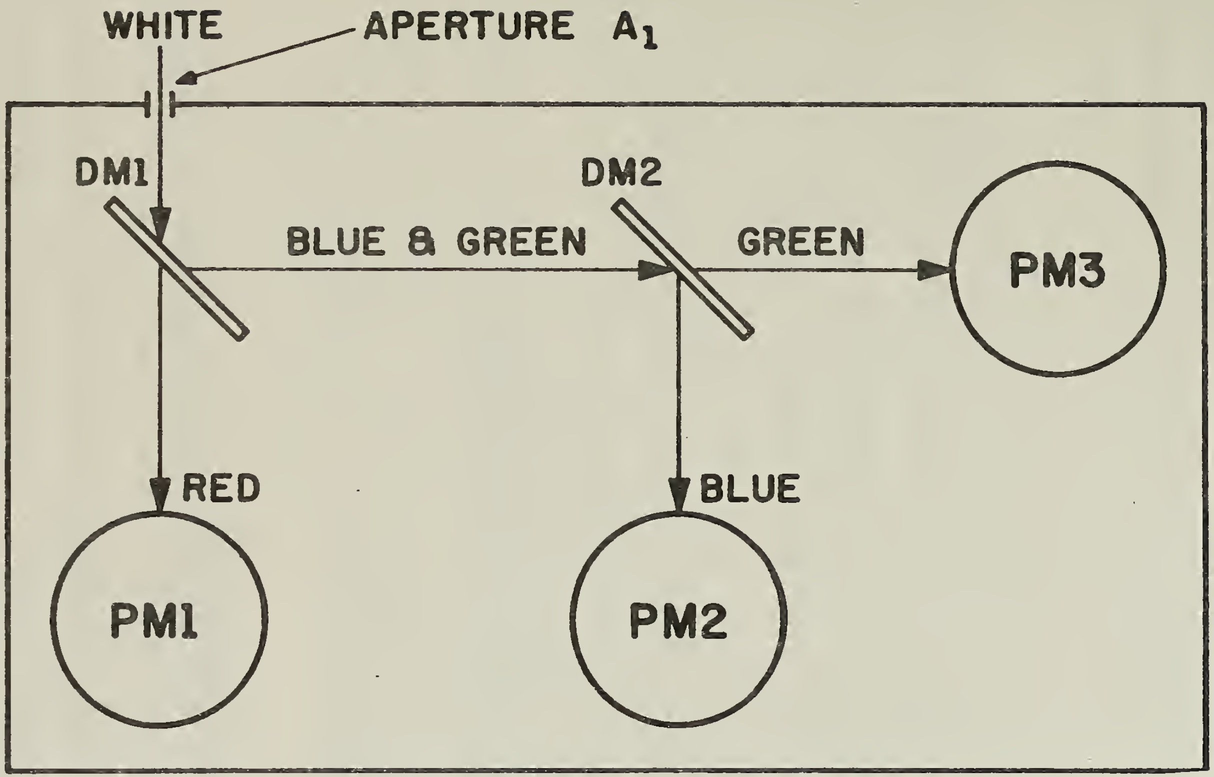


Figure 3. Photomultiplier Assembly

"primary colors," thus generating the three video signals corresponding to the colors red, blue and green at the output of the photomultipliers PM_1, PM_2 and PM_3.

The lenses and the vibrating (scanning) mirrors form the optics of the scanner. The lenses are arranged such that the image of the television tube (picture) is formed at the operture A_1. The scanning mirrors enable different portions of the picture to be imaged at A_1 thereby scanning the entire picture when vibrating.

Since the vertical and horizontal vibrating frequencies are different from those of the receiver, the television screen must act as the picture memory until the scanning mirrors detect the picture information. All color CRT screens are coated with phosphors which could presumably act as a picture memory. The light output from phosphors has a decay time (i.e. the picture intensity fades exponentially in time). This fading may be electronically compensated for by amplifying the photomultiplier signal by a gain which is an exponential function of the difference between the time the picture was formed and the time it was detected by the photomultipliers. This correction would eliminate the dark and bright horizontal bands in the final picture.

3.2 Modulation System

The modulation system is essentially the same as that described later in Section 4 except that the light source to be used was an arc lamp collimated to give a narrow beam. Polarizers were used at the output of the arc lamp to get the polarized beam necessary for the EOLMs.

3.3 Deflection System

The deflection system is the same as that described in Section 5.

The mirrors are driven by the same driver circuits that drive the scanning mirrors. This ensures that the scanning is in synchronism with the projection.

3.4 Difficulties

As was mentioned earlier, this approach was abandoned for the following reasons:

3.4.1 Light Source:--The schematic of the light source is shown in Figure 4. The EOLMs and the required picture resolution impose a limit on the maximum diameter and maximum divergence of the output beam. The aperture of the EOLM is 3mm; thus the maximum diameter of the beam (d_1) must not exceed 3 mm in order to avoid losses.

The resolution (number of resolvable spots on the projected picture) was fixed at 100 spots. This is determined by the ratio

$$\text{Number of resolvable spots} = \frac{\text{2 x peak-to-peak deflection angle of the deflection mirror}}{\text{divergence angle of the beam } (\phi_3)}$$

The horizontal peak-to-peak deflection angle is 3°, thus implying that ϕ_3 must not exceed 1 milliradian. The calculations of the light source are shown in Appendix III. The result is:

$$\frac{\text{The light flux in the collimated beam}}{\text{The light flux emitted by the arc}} = \frac{1}{16} \frac{d_1^2}{S^2} \phi_3^2$$

where S is the approximate size of the arc. Substituting some realistic figures into the above result we get

$$\frac{\text{The light flux in the collimated beam}}{} = \frac{1}{16} (\frac{3}{5})^2 \times (.001)^2$$

$$\simeq 2.25 \times 10^{-8}$$

If the needed light flux in the collimated beam is 200 lumens, the arc

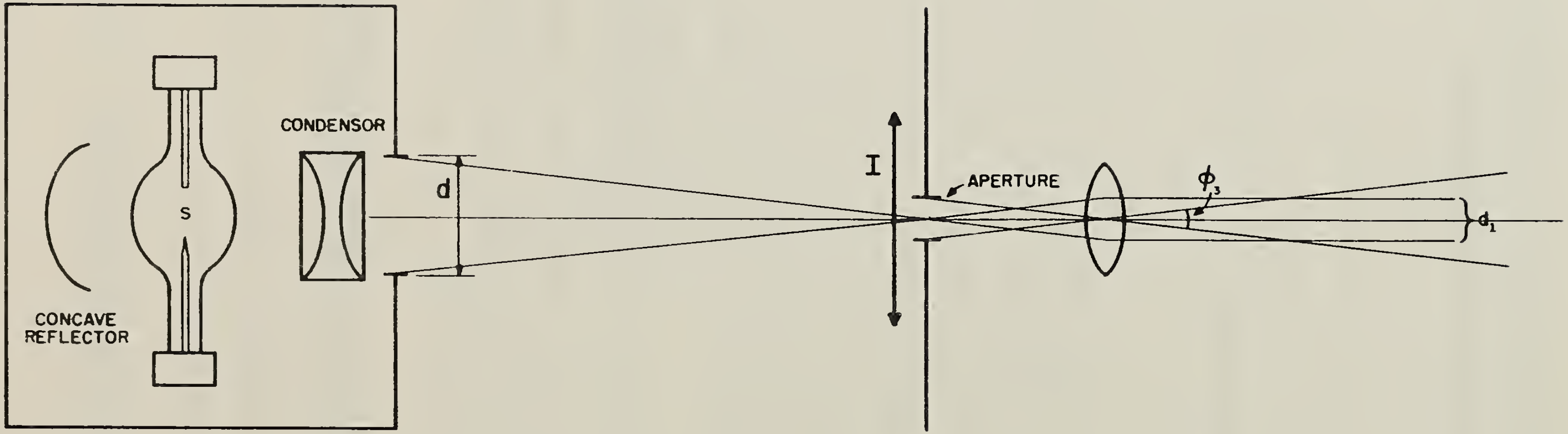


Figure 4. The Arc Source

should put out 450×10^8 lumens. This exceeds the light flux available from the brightest available arc lamp.

3.4.2 Phosphor Characteristics:--It was noted earlier that the phosphor of the television screen must act as a picture memory for the duration of time between the time the picture is formed and the time it is picked up by the scanning mirror. This requires that the phosphor decay time be of the order of a few milliseconds. The rapid advances in phosphor materials and technology have reduced the phosphor decay times to a few microseconds. The result is that a modern color picture tube coated with P22 phosphor has an average decay time of approximately 20 to 50 μsecs. This time is shorter than the scanning time of one line in the picture. Thus, the phosphor cannot be used as a picture memory.

The above mentioned problems caused this approach to be abandoned.

4. MODULATION SYSTEM

This subsystem receives the video and chroma signals from the television receiver as its input and produces intensity modulated light beams (red, green and blue) at its output. The light source used is a Spectra Physics Model 164 Argon-Krypton laser. The laser produces at least 250 mw at blue (4880 A°), green (5145 A°) and red (6471 A°). The beam is in the TEM_{00} mode except for the blue component where the TEM_{01} mode is tolerated. This is tolerable because the blue component, being of shorter wavelength, has a smaller diffraction limited spot than the green or red components. Therefore, the higher older transverse mode results in a spot which just coincides with the TEM_{00} of the green and red components. The laser beam is vertically polarized, has a divergence of 0.5 milliradians and has an output beam diameter of 1.5 mm. The intensity calculations for the laser are given in Appendix I.

4.1 Modulation Optics

Figure 5 is a schematic of the optics of the modulation system. The mirrors, M_1 and M_2, are front surface mirrors and are used only for the deflection of the laser beam. CR is a corner reflector which has two-front surface mirrors mounted at right angles. It is used to rotate the plane of polarization of the laser beam by 90°. This rotation of the plane of polarization is necessary for the following reasons.

The output beam of the laser is polarized in the vertical plane. When this beam strikes the prism surface (which is also in the vertical plane) there will be reflection losses. For the given polarization, the coefficient of refelction from a dielectric surface with oblique incidence is given by the formula(7)

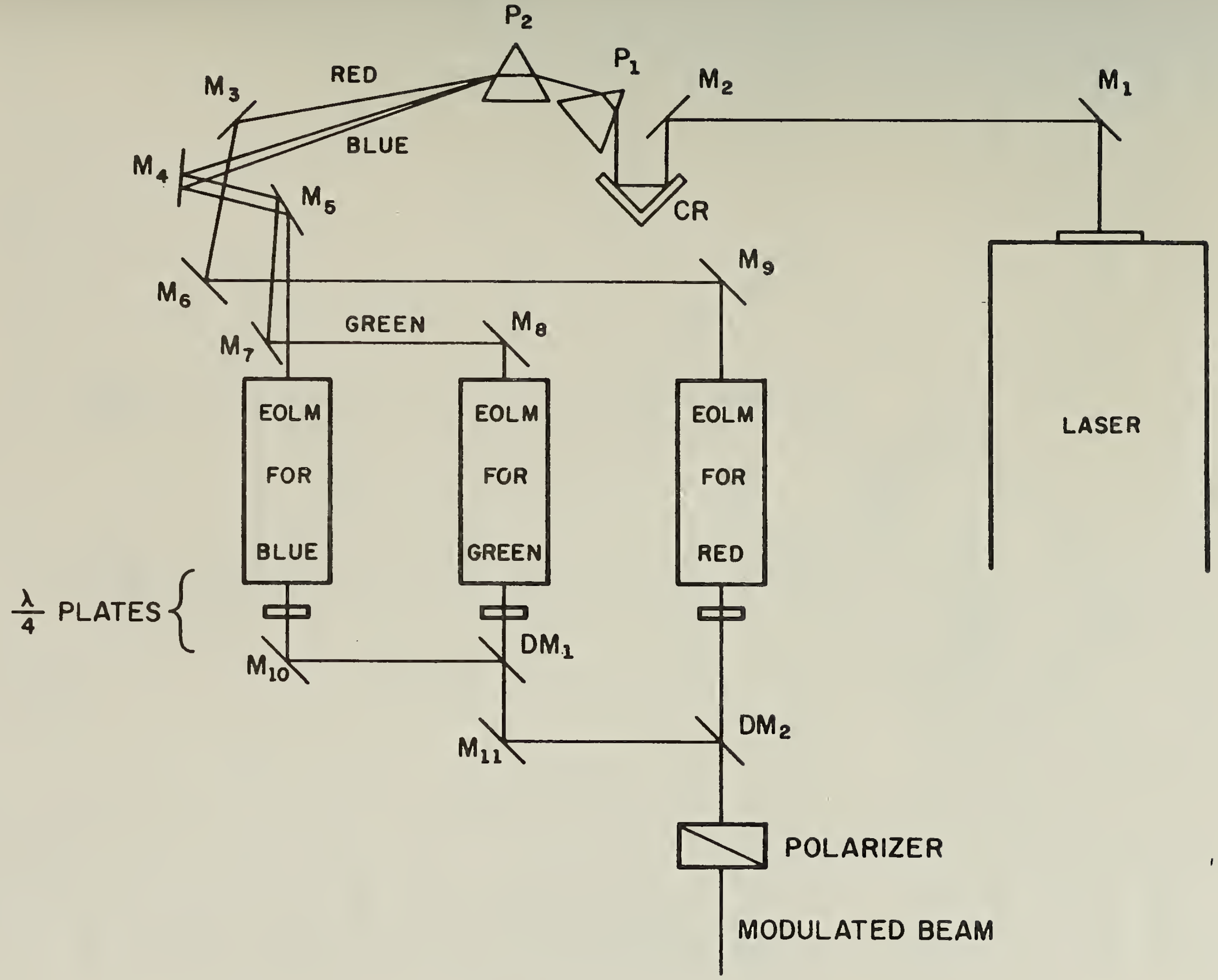


Figure 5. Modulation Optics

$$R = \frac{E_r}{E_i} = - \frac{\sin (i-r)}{\sin (i+r)}$$

Where i and r are the angle of incidence and the angle of refraction respectively. It can be shown that for $0 < i < \pi/2$ the coefficient of reflection R increases monotonically with i (i.e. there is no occurrence of a "Brewsters angle"). However, if the polarization of the laser beam is rotated by 90° (i.e. beam is made polarized in the horizontal plane) the coefficient of reflection is given by

$$R = \frac{\tan (i-r)}{\tan (i+r)}$$

It is seen that $R = 0$ when $i + r = \frac{\pi}{2}$ (the condition for Brewsters angle θ_B, $\tan \theta_B = n$. If a laser beam with horizontal polarization is made incident on the prism surface at an angle θ_B, then there is no reflection loss. Thus by rotating the polarization of the laser beam by 90° we can eliminate reflection loss at one surface of the prism. There is another surface of the prism, at which the beam goes from the glass to air and a reflection loss is encountered there too. Therefore, the angle of incidence is kept such that the sum of the losses at the two surfaces is minimum. The details are given in Appendix II. In this manner the corner reflector rotates the plane of polarization of the laser beam by 90°. Figure 6 shows how the rotation is accomplished. Since there is some loss at the reflecting surfaces (due to the finite resistivity of the coated material) the outgoing beam has a little ellipticity.(7) This does not pose any problem since the vertically polarized component suffers very high loss at the prism surfaces resulting in an almost horizontally polarized beam at the output of the prisms.

The laser beam then falls onto the prisms P_1 and then P_2. These are used to disperse the multimode laser beam into its various color

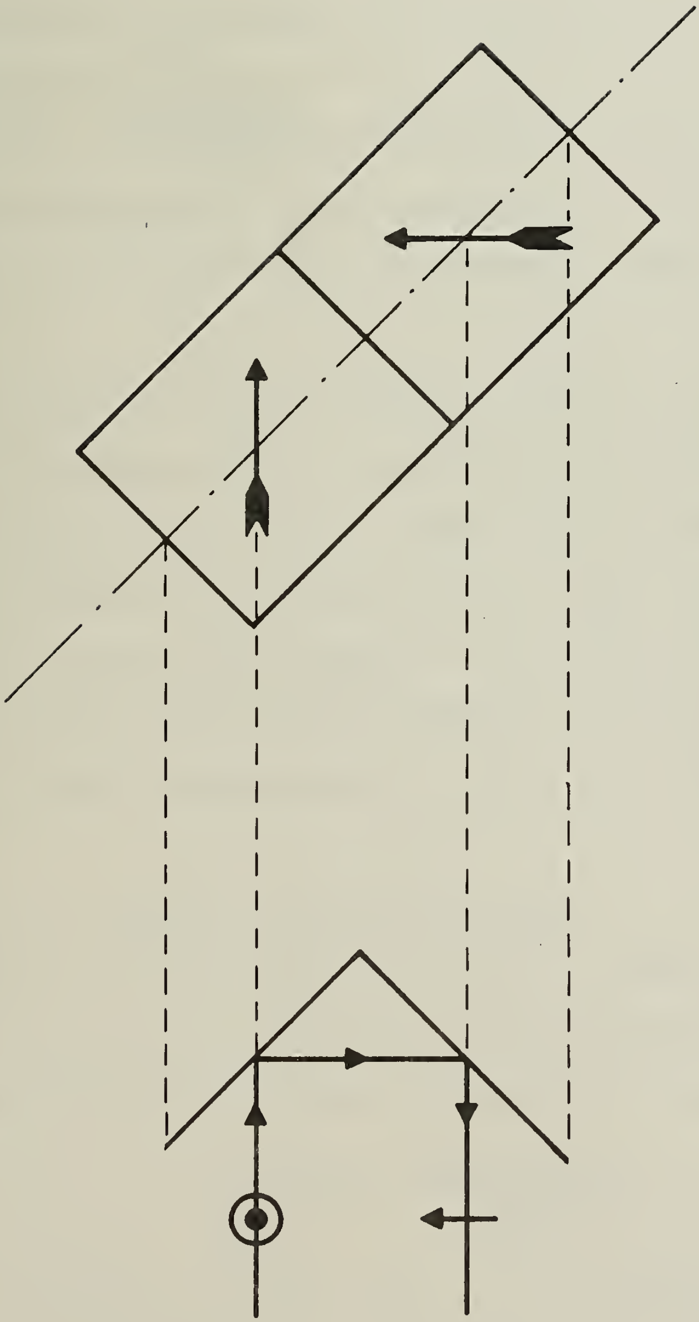


Figure 6. Corner Reflector

components. Two prisms are used to achieve a larger angular spread between the adjacent color components. In both prisms the angle of incidence is made such that the total refelction loss is minimum.

The mirrors M_3 - M_9 are front surface mirrors on adjustable mounts. The front end of the modulation system is considered aligned when the beams fall on their respective EOLMs and the reflected beam (a very small fraction of the incident light will be reflected from the surface of the EOLM) coincides with the path followed by the incident beam.

On the output end of the EOLMs the front surface mirror M_{10} directs the blue beam to the dichroic mirror DM_1, which reflects the blue beam but transmits the green beam. When the outgoing beams (blue and green) from DM_1 coincide and give only one spot on screen, the mirrors M_{10} and DM_1 are considered to be aligned. The mirror M_{11} is also a front surface mirror and it directs the blue-green beam to the dichroic mirror DM_2 which reflects blue and green beams and transmits the red beam. When all the beams coincide to give only one spot on the screen, the mirrors M_{11} and DM_2 are considered to be aligned.

The $\lambda/4$ plates ($\lambda = 5145$ A°) are inserted into the paths of the beams for the following reason. The EOLMs have the transmission characteristics given by (assuming no loss due to reflection or absorption):(8)

$$\frac{I_{TRANSMITTED}}{I_{INCIDENT}} = \sin^2\left(\frac{\pi}{2}\frac{V}{V_{\lambda/2}}\right)$$

For the EOLMs used, $V_{\lambda/2} = 365$ volts at $\lambda = 5145$ A°. Thus, to get full transmission of green light (5145 A°) the applied voltage V must be equal to $V_{\lambda/2}$($V = V_{\lambda/2} = 365$ volts). This is an inconvenient operating voltage for the solid state driver circuit at video frequencies. In order to use solid state circuits, it is convenient to have the modulating video signals swing between -200 to +200 volts. The EOLMs must then be biased correspondingly. Biasing electronically would be one solution. A more elegant way of doing it is to introduce a $\lambda/4$ plate in the path of the beam. This modifies the transmission characteristics of EOLM to

$$\frac{I_{TRANSMITTED}}{I_{INCIDENT}} = \sin^2\left(\frac{\pi}{2}\frac{V}{V_{\lambda/2}} + \frac{\pi}{4}\right)$$

This characteristics has full transmission at $V = \frac{V_{\lambda/2}}{2}$ and has no transmission at $V = \frac{-V_{\lambda/2}}{2}$. This characteristic makes the use of a differential driver advantageous. It is worth nothing that the $\lambda/4$ plate will have quarter wave retardation only at 5145 A°. For 4880 A° and 6471 A° the retardation will be slightly different. This difference is offset by appropriate electronic bias applied to the EOLMs.

The application of the video driving voltage across the EOLM will phase modulate the incoming light beam. This phase modulated beam is converted into an intensity modulated beam by the Glan prism polarizer (P) which is used at the output end of the modulation system.

4.2 The Electronics of the Modulation System

Figure 7 gives the schematic of the electronics of the modulation system. The signals B-Y, G-Y and R-Y are obtained from the output of the chroma demodulator of the television receiver. Since these signals have amplitudes and d.c. levels different from those required, they are amplified and shifted in d.c. level by the video amplifiers VA_1, VA_2 and VA_3. The video Y (luminance) signal is obtained from the video amplifier of the television receiver. The Y signal is amplified and shifted in d.c. level by the video amplifier VA_4. The luminance signal Y is added to the chroma signals B-Y, G-Y, and R-Y in the proper proportion to obtain the blue, green and red video signals. This addition is done by the

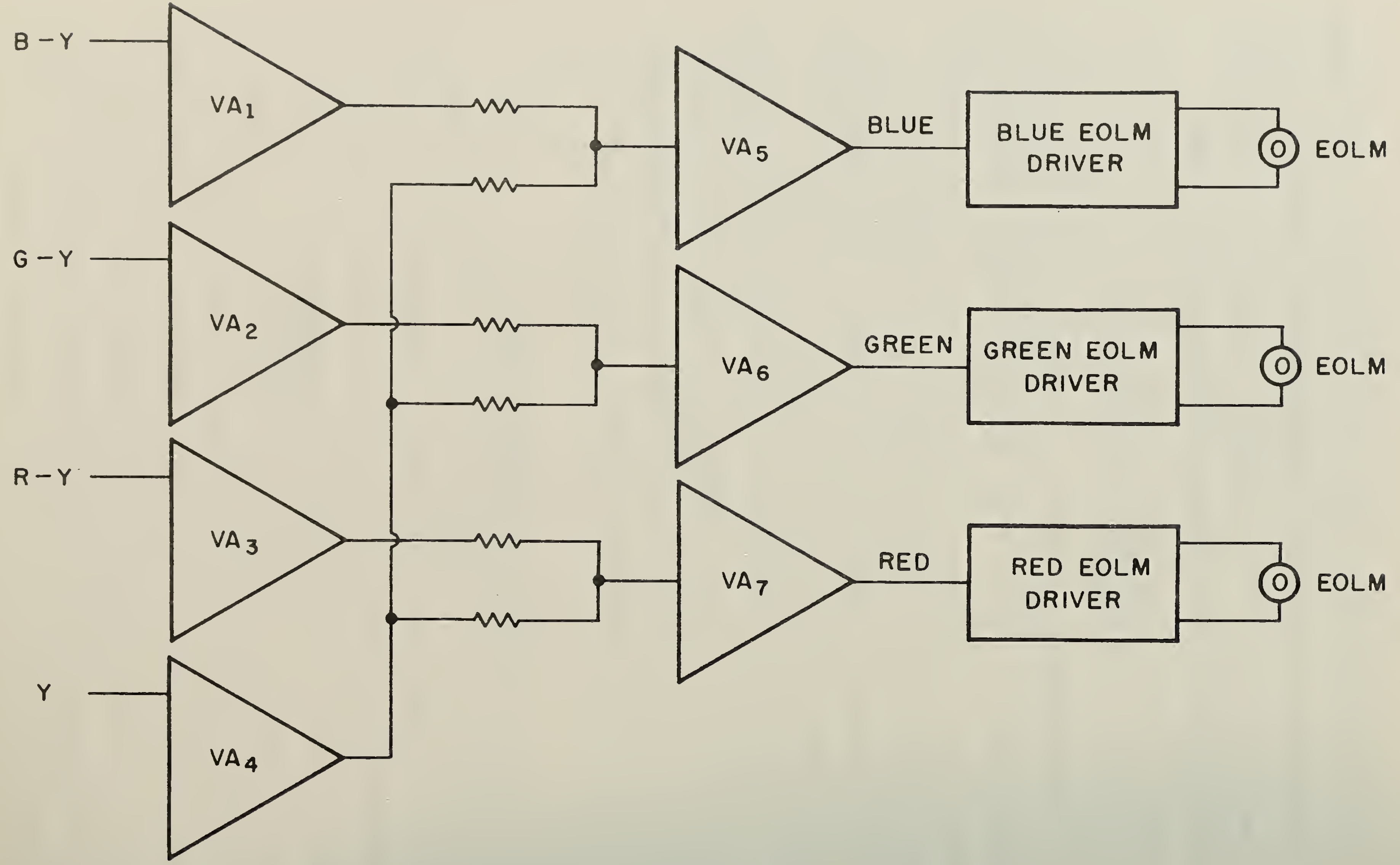


Figure 7. Electronics of the Modulation System

matrixing resistance network. These blue, green and red video signals are obtained at the output of video amplifiers VA_5, VA_6 and VA_7 respectively. These video signals are used as the inputs to the EOLM drivers.

4.3 The EOLM Driver

The circuit of the EOLM driver is shown in Figure 8. The driver is basically a cascade differential amplifier. The transistors T_1 - T_3 and T_2 - T_4 form two darlinton pairs of the lower portion of the cascade differential amplifier. The transistors T_7 and T_8 form a current source which can be adjusted by means of the "current adjust" potentiometer. The driver receives its input from the video amplifiers generating any of the blue, green or red signals. The voltage level of this signal is shifted by means of the zenner diode D_1. When the blanking signal level is at -15 volts, transistor T_1 receives the input video signal. When the blanking signal is at -9 volts, transistor T_1 cuts off and T_2 conducts heavily, thus producing a constant voltage (irrespective of the video signal) at the output. The "Bias adjust" resistor provides the constant electronic bias to the EOLMs when necessary, as discussed in Section 3.1.

The upper portion of the cascade differential amplifier is formed by the transistors T_5 and T_6. These are high voltage, high power, high frequency transistors. The driven EOLMs have a terminal capacitance of 20 pf to which we add the cable capacitance of approximately 60 pf giving the total capacitance of 80 pf. The inducters L_1 and L_2 are peaking coils designed for a flat frequency response up to 4.00 MHz. The output of the driver swings between -200 to +200 volts (with no bias). A very careful shielding of the various stages of the video amplifiers, power supply lines and the driver output lines is necessary to avoid oscillations due to feedback.

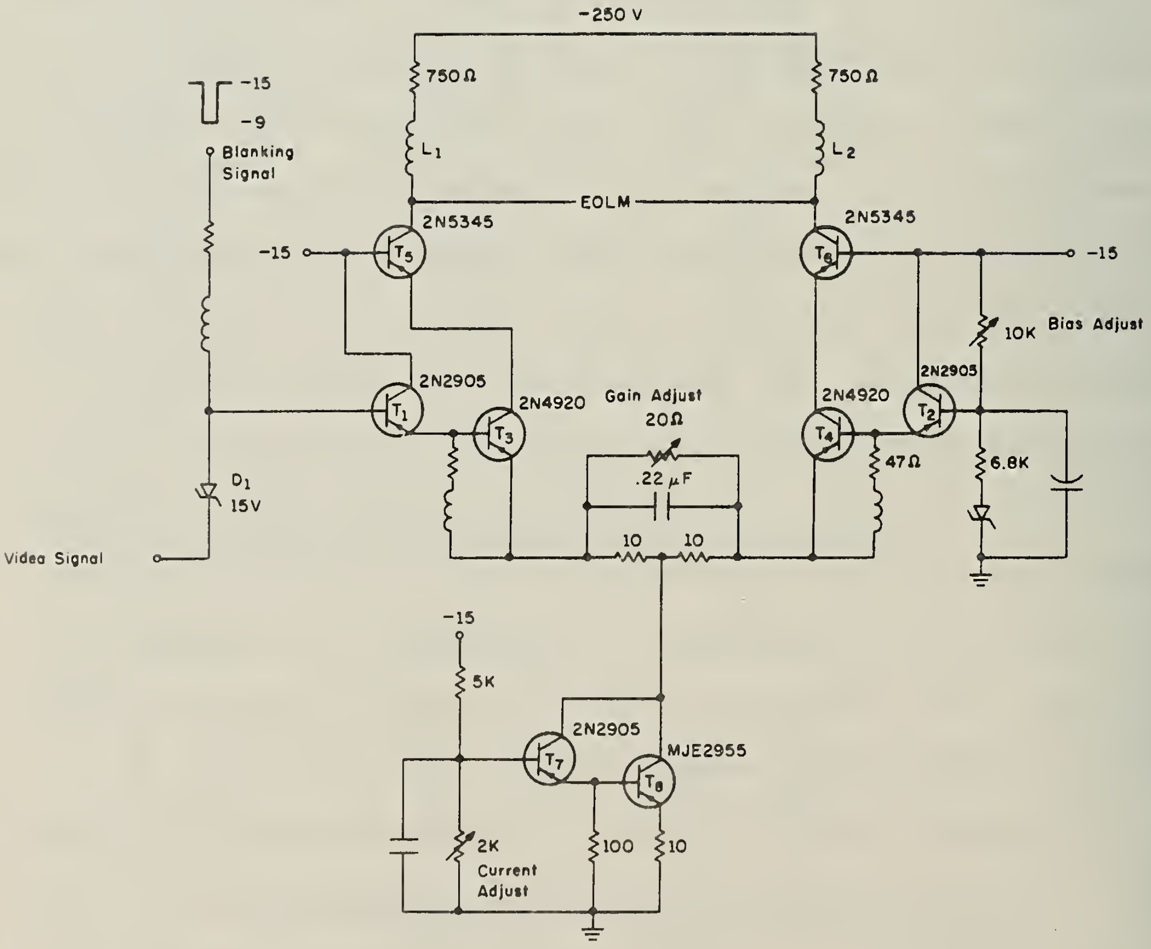


Figure 8. EOLM Driver

The EOLMs are blanked during the vertical and horizontal retrace period of the scanning process. The blanking signal is generated by a combination of vertical and horizontal synchronizing signals and is discussed in detail in the next Section.

5. DEFLECTION SYSTEM

This subsystem of LASCOT produces the deflection of the laser beam to form the raster. This raster is synchronized to that of the television receiver. This subsystem also generates the Blanking waveform.

5.1 Deflection Optics

A top view and a side view of the deflection optics is shown in Figure 9. The intensity modulated light beam emerges from the polarizer (P) as the final output of the modulation system. The mirror M_{12} is a front surface mirror. The light beam has a diameter of approximately 3 mm. Since this is very large compared to the dimensions of the horizontal deflection mirror (HM), the beam must be converged so that the entire beam falls onto the mirror HM if no light is to be lost. Therefore, the achromatic lens L_1 is introduced into the optical path. The focal length of L_1 is 800 mm. It is chosen such that the beam diameter at HM is less than 0.025 inches, the width of the horizontal deflection mirror.

The horizontal deflection mirror (CEC Model 7-366) is a galvanometer type vibrating mirror. It has a peak-to-peak deflection of 3° and a flat frequency response up to 25 KHz. The size of the mirror is 0.035" x 0.025," its sensitivity is 21 mA per degree and it has a terminal resistance of 112 ohms. This mirror is mounted in a permanent magnet, which produces rotation of the movable coil when a current is passed through it.

The horizontal scanning frequency in commercial television is 15.75 KHz. This means that if the horizontal deflection mirror is made to follow the television horizontal deflection waveform, it would have to vibrate at 15.75 KHz and, in addition, the deflection must be of a sawtooth type. This is not possible with available gavanometer mirrors since

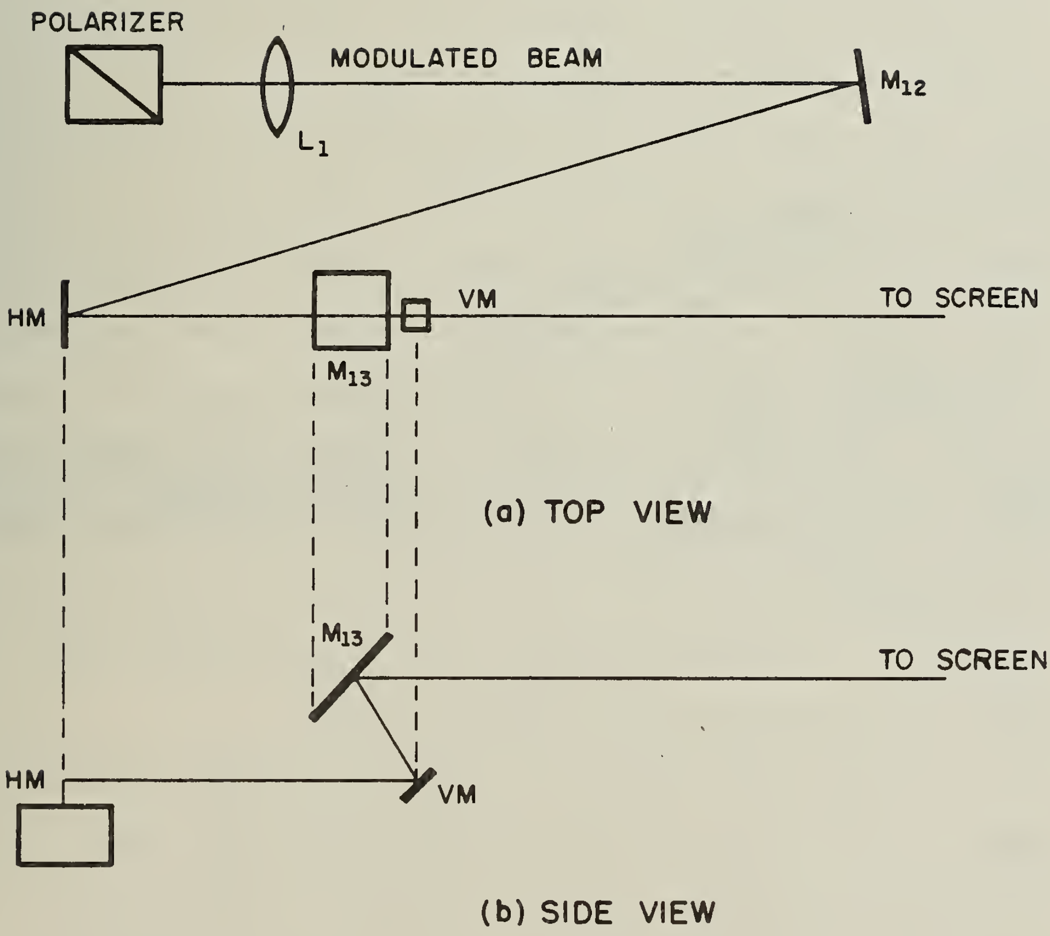


Figure 9. Deflection Optics

a sawtooth waveform of 15.75 KHz has 2nd, 3rd and higher harmonics to which the mirror cannot respond. Therefore, it was decided to scan at a rate which is one half that of commercial television, i.e. 7.875 KHz. The deflection waveform is triangular rather than sawtooth. This has the advantage that the third harmonic of 7.875 KHz is within the region of flat frequency response thereby rendering the scan more linear. This, of course, implies that every alternate line of the television picture must be omitted. The beam is blanked during that time (retrace). There is also a delay (phase shift) between the driving waveform and the deflection of the horizontal deflection mirror. If this delay is allowed to remain, the raster will not be in step with the video waveform. The result is that the picture formed on the screen does not begin at the beginning of the raster line but somewhere else depending on the amount of delay. This produces a horizontally "wrapped around" picture. The effect is easily eliminated by electronically delaying the driving waveform by the amount of the delay such that the video waveform and the raster are in step thus giving the correct picture on the screen. The details are discussed in the following sections.

The beam, after reflection from HM falls on VM. The vertical deflection mirror (VM) is a General Scanning Model G-0606 which is also of the galvanometer type. It has a bandwidth of 1.5 KHz, a peak to peak deflection f 12° and has a deflection sensitivity of 250 ma/degree. The size of the mirror is 1/2" square. The mirror has a terminal resistance of 6 ohms and an inductance of 2 mH. The VM has sufficiently high frequency response to include all significant higher harmonics of the horizontal deflection waveform which is sawtooth in shape and has a frequency of 30 Hz. The beam is blanked during the retrace. The reflected beam from VM falls on M_{13} and then onto the screen.

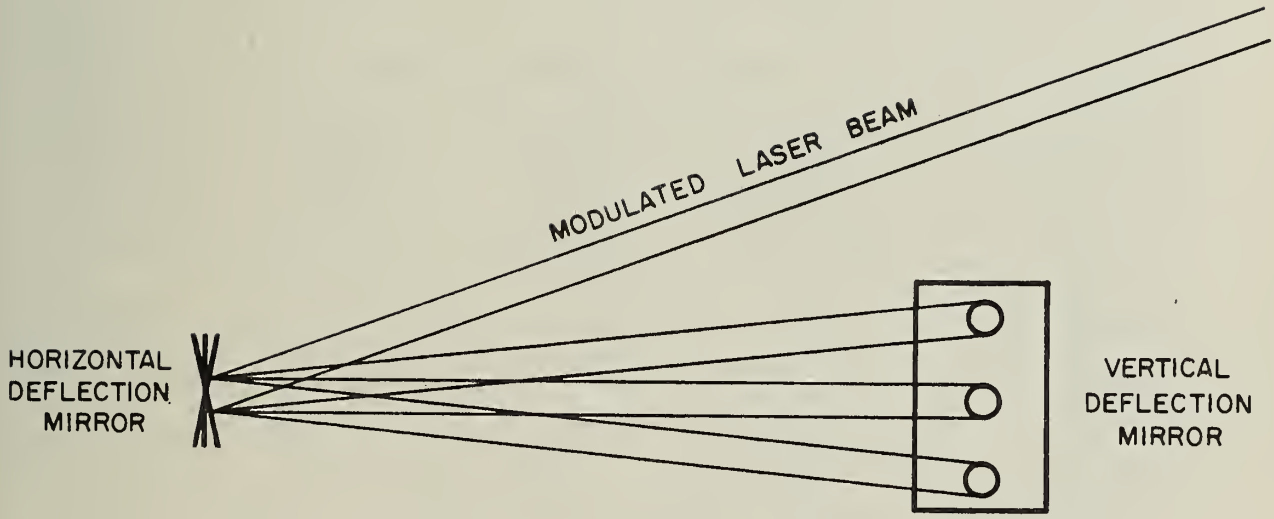


Figure 10. Horizontal Deflection Details

The screen is a beaded glass type. It has a gain of 3 within a viewing angle of ±25°. This high gain screen is used to enhance the brightness of the picture.

5.2 Electronics of the Deflection System

5.2.1 Horizontal Deflection

The schematic diagram of the circuit is shown in Figure 11. The horizontal synchronization pulses are derived from the horizontal oscillator of the television receiver. As noted earlier, there is a relative delay between the deflection waveform and the deflection of the mirror. This is offset by the monostable D_1 which is adjusted to a value such that the deflection waveform leads the synchronization pulses by the same amount as the mirror lags behind the deflection waveform. Thus the combined effect of lead and lag tend to nullify each other giving a raster that is in step with the video. A scaling flipflop, FF_1, is used to scale the horizontal deflection frequency of 15.75 KHz to 7.875 KHz. This is necessary for the reasons discussed earlier. This waveform is fed to the horizontal driver as shown in Figure 12.

The circuit of the horizontal driver consists of a switched current source and current sink which alternately charge and discharge the capacitor C_1, producing a triangular wave across the it. The current source consists of the transistor T_3 with its emitter resistor and base bias. T_3 is turned on or off by transistor T_1. Similiarly, the current sink consists of the transistor T_4 with its emitter resistor and base bias. T_4 is turned on or off by transistor T_2. If a square waveform exists at the input, only one of T_3 and T_4 is on at any instant. The triangular waveform across C_1 is fed to the output stage consisting of T_5, T_6, T_7

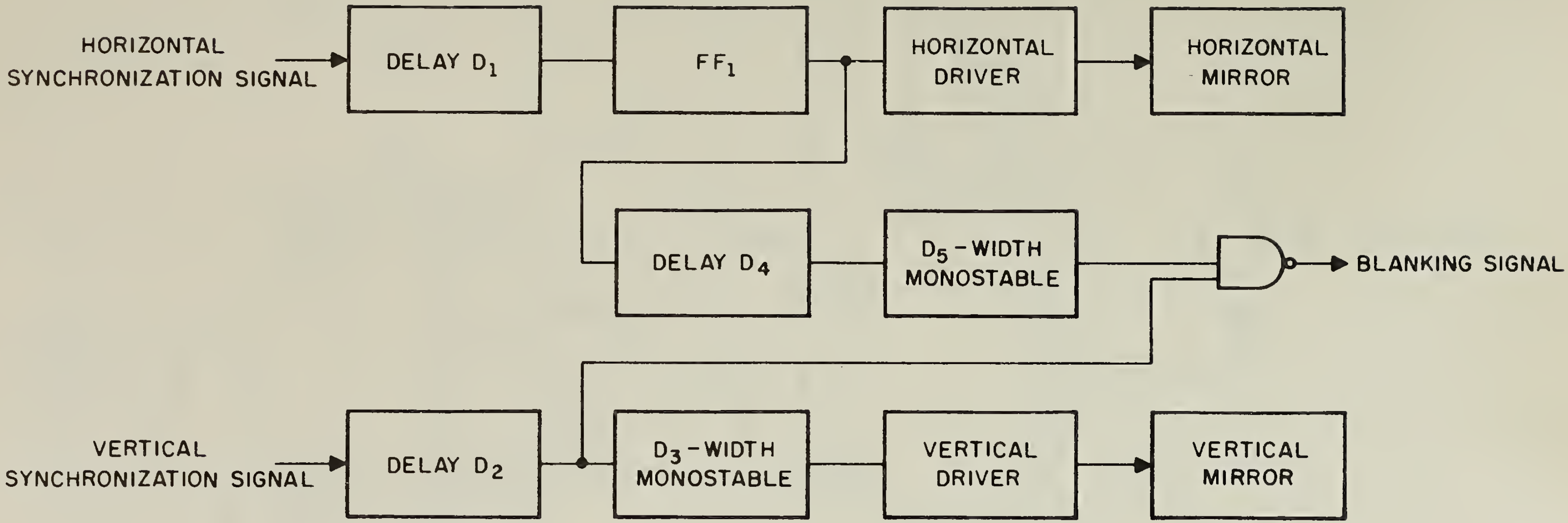


Figure 11. Electronics of the Deflection System

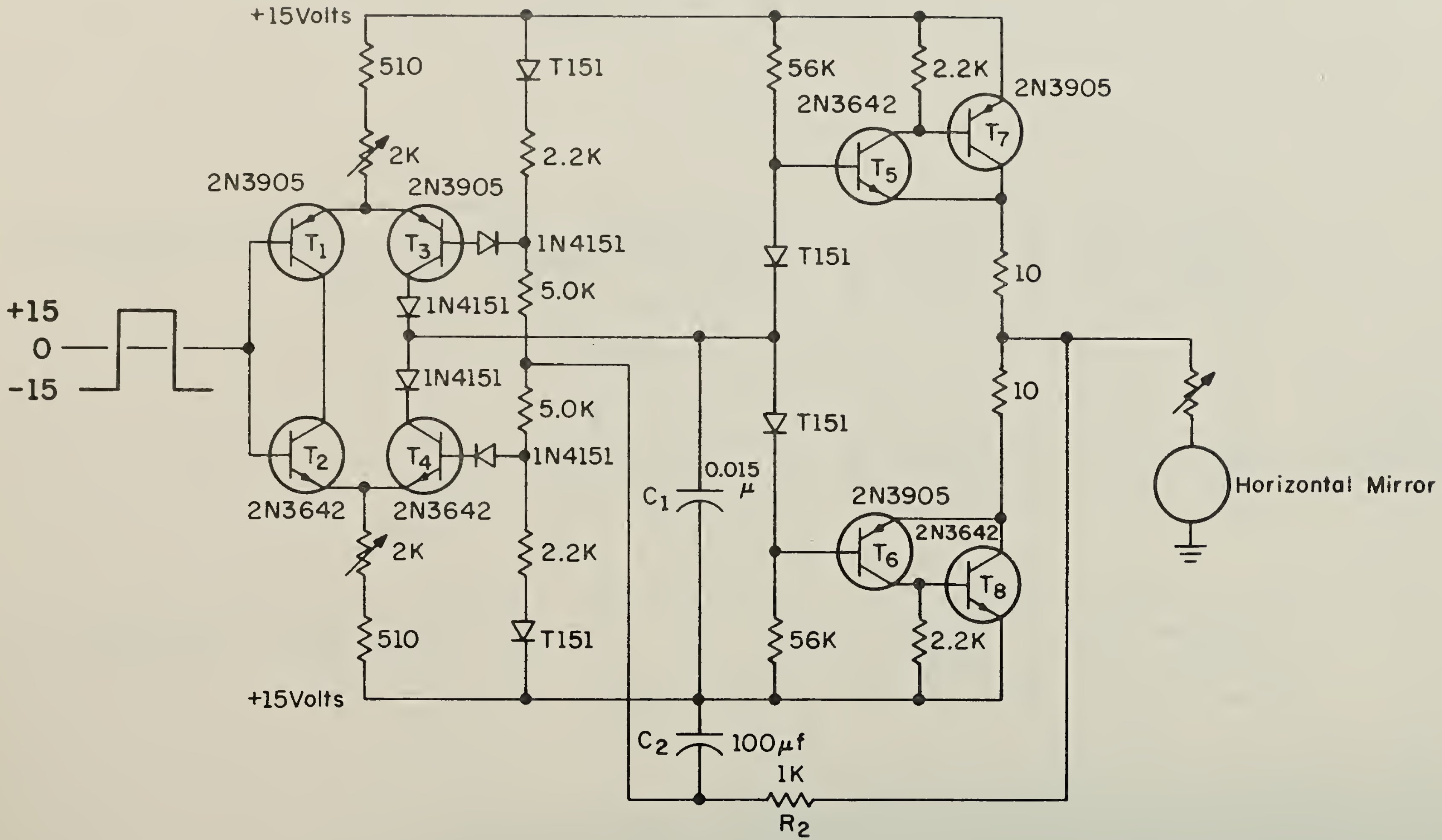


Figure 12. Horizontal Driver

and T_8. It provides a low impedence (112 ohms terminal resistance) output to drive the horizontal deflection mirror.

A stable, symmetric, triangular wave is obtained at the output only if the magnitude of the current source is exactly equal to that of the current sink. If they differ in magnitude, there is a net positive or negative charge deposited on C_1 in every cycle causing the waveform to drift in its d.c. level. This is corrected by the feedback network R_2C_2 which allows only the d.c. level of the driver to appear at the midpoint of the bias network causing the base bias of the current source-sink to change in such a way so as to correct for any drift in d.c. level.

5.2.2 Vertical Deflection

Referring to Figure 11, the vertical synchronization pulse is obtained from the vertical oscillator of the television receiver. The monostable D_2 offsets the time lag between the edge of the synchronization pulse and the beginning of the frame. The monostable D_3 gives a pulse width equal to the vertical retrace time. This waveform is sent to the vertical driver whose circuit is shown in Figure 13. This driver is similiar to the horizontal driver except that the value of the current source is not the same as that of the current sink thus giving a sawtooth waveform across the capacitor C_1. The ratio of the current source to current sink is kept the same as the ratio of the deflection time to retrace time as determined by the pulse width of the output waveform of D_3. This gives a stable sawtooth waveform. The output stage has a very high current handling capacity because the vertical deflection mirror requires 250 ma/degree of deflection. The d.c. level of the output waveform is fed back to the biasing network by the filter network R_2C_2, for the reasons discussed earlier.

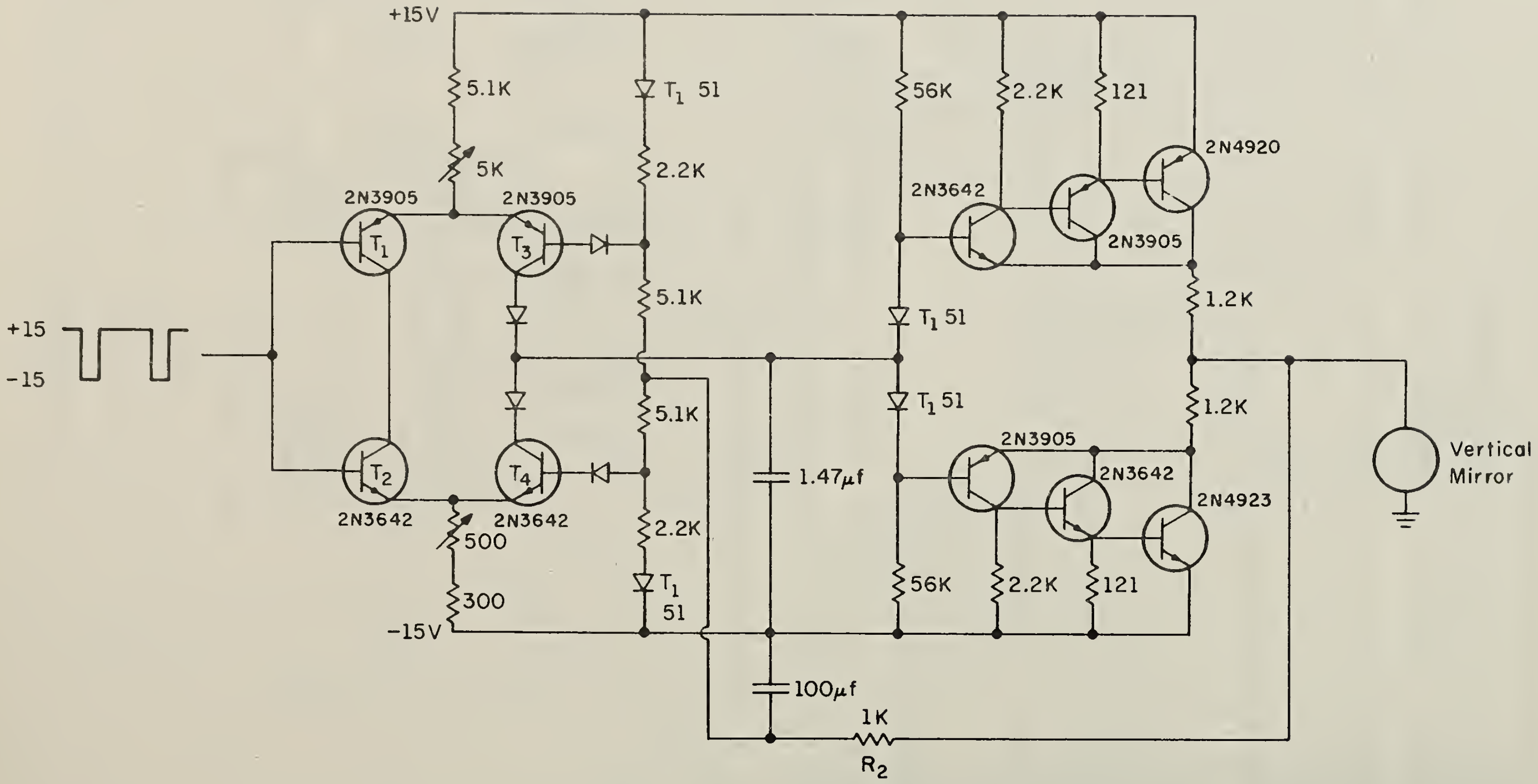


Figure 13. Vertical Driver

5.2.3 Blanking Generator

The blanking generator shown in Figure 11 generates the blanking signal which is then fed to the EOLM driver to blank out the beam during horizontal and vertical retrace. It was pointed out in the discussion of the horizontal deflection that the deflection waveform was given a leading phase to offset the mirror lag. Since the blanking must correspond to the video the output of the flipflop is delayed by the monostable D_3 to offset the leading phase given by D_1. The monostable D_5 gives the necessary pulse width for horizontal blanking. The vertical blanking is derived from the output of D_3. These waveforms are fed to an OR gate to obtain a combined blanking signal.

6. SUMMARY

A color television display system has been designed and constructed using a mixed gas (Argon-Krypton) laser as the light source. Intensity modulation of the three "primary colors" is accomplished by using electro-optic light modulators. The deflection of the beam is performed by galvanometer type vibrating mirrors. The picture formed by this display has the following characteristics (Laser output power = 0.6 watts)

Size of the picture (at a distance of 9')	= 2' x 1.5'
Spot size	0·18"
Screen luminance	0·5 foot lambert
Resolution	Horizontal:- 120 lines, Vertical:- 100 lines
Contrast ratio	25

It can be seen that the above characteristics are acceptable for a large screen television. The screen luminance can be increased simply by using a higher power laser and better quality optical components.

In comparison with other large screen color displays, this display system uses components which are readily available in the market; it does not require any custom made components i.e., modulator block, oil film light value, etc. This display system is also less costly than the other large screen color display systems. On the other hand, this system has lower resolution than the other large screen color display systems. With improvements in laser technology, high wattage lasers will be available and thus the size and the intensity of the picture may be increased. This display also suffers from another drawback which is common to all laser displays, i.e. the primary blue is very pale blue and does not coincide with the peak of P22 phosphor (4500 A° approx.).

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APPENDIX I

Laser Power Calculations. In this section we shall calculate the screen luminance caused by the laser beam with 250 m watts of power in the blue (4880 A°), green (5145 A°) and red (6471 A°) colored components.

The transmission of the optical components used in the system are as follows:

(1) Front Surface Mirrors = 0.95
(2) Two prisms = 0.84
(3) Modulators = 0.80
(4) $\lambda/4$ plate = 0.92
(5) Dichroic Mirror = 0.75
(6) Polarizer = 0.85
(7) Lens L_1 (coated) = 0.98
(8) Horizontal deflection mirror = 0.90
(9) Vertical deflection mirror = 0.95
(10) Recovered after diffraction = 0.85

We notice that the blue and the green beam encounters two dichroic mirrors whereas the red beam encounters only one. Also all beams, on the average, encounters 13 front surface mirrors.

The total transmission for blue and green beams = 0.106

The total transmission for red beam = 0.142

It must be noted that the beam is blanked during horizontal and vertical retrace time thus reducing the light energy reaching the screen. The horizontal blanking cuts off the beam for 53% of the time also the vertical blanking cuts off the beam for 8% of the time; giving the blanking factor = 0.47 x 0.92 = 0.433.

The output power of the blue beam = 250 x 0.106 x 0.433 = 11.4 m watts

The output power of the green beam = 250 x 0.106 x 0.433 = 11.4 m watts

The output power of the red beam = 250 x 0.142 x 0.433 = 15.3 m watts

From Figure 14 we obtain the lumens-per-watt factors for the three colors used. Thus the light flux (in lumens) of various colors is

Light flux in blue (4880 A°) = 11.4 x 108 = 1.23

Light flux in green (5145 A°) = 11.4 x 315 = 3.60

Light flux in red (6471 A°) = 15.3 x 105 = 1.61

These lumens can be thought of as distributed over the entire picture size of 4' x 3', by means of a diverging lens, thus producing a constant illumination over the screen. This process is similiar to the beam spot scanned all over the picture size (4' x 3') in which the persistence of the eye acts as an averaging device which averages the spot intensity (for the dwell time of the spot) over the entire frame period.(9,10)

The screen illuminance for blue = 1.23/12 = 0.1025 footcandles

The screen illuminance for green = 3.60/12 = 0.3 footcandle

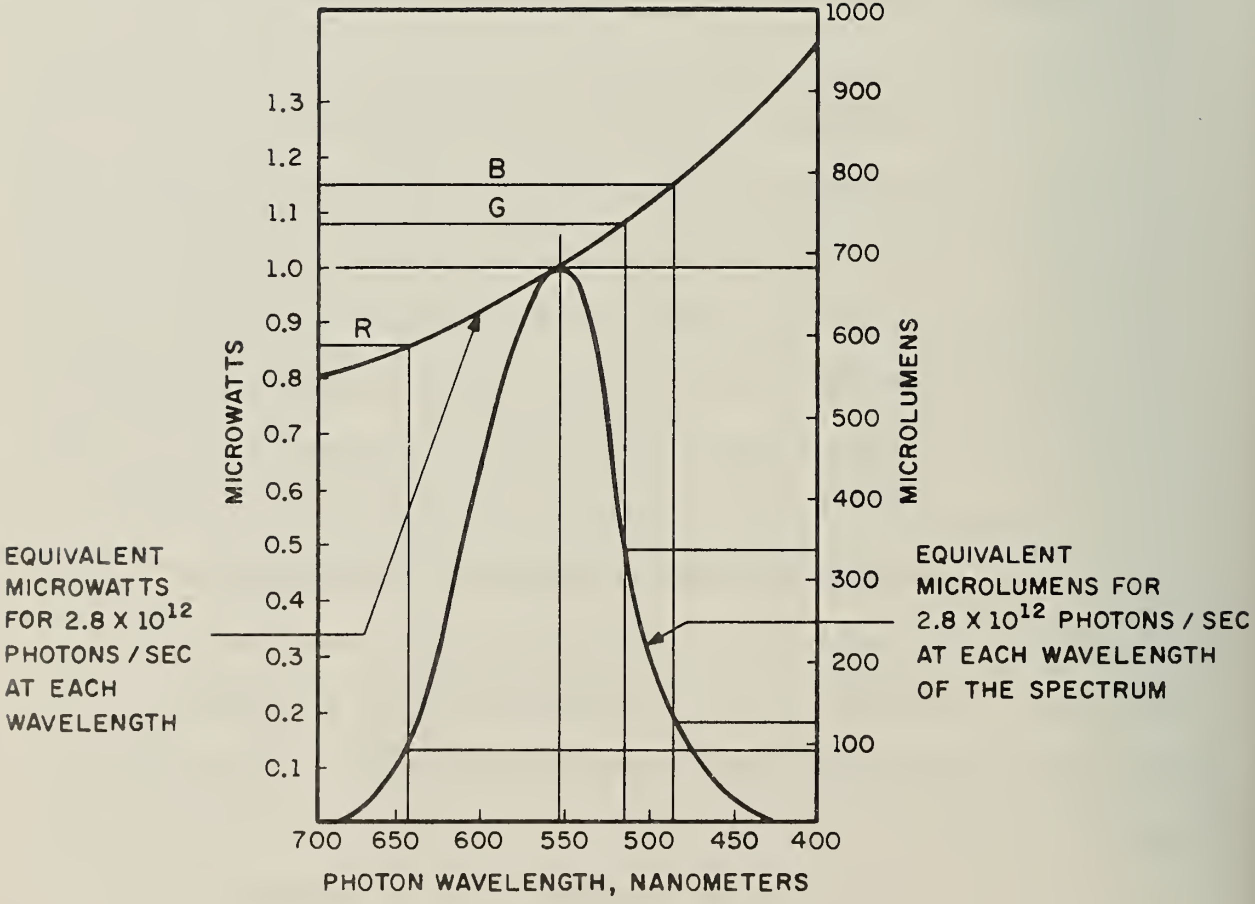
The screen illuminance for red = 1.61/12 = 0.134 footcandle

Using the beaded screen which has the gain = 3, the screen luminance for the three colors is

Screen luminance for the blue = 0.1025 x 3 = 0.375 footlamberts

Screen luminance for the green = 0.3 x 3 = 0.9 footlamberts

Screen luminance for the red = 0.134 x 3 = 0.402 footlamberts



$$B\ (4880\ \text{A}^\circ) = \frac{125}{1\cdot 15} = 108\ \text{LUMENS/WATT}$$

$$G\ (5145\ \text{A}^\circ) = \frac{340}{1\cdot 08} = 315\quad "\quad "$$

$$R\ (6471\ \text{A}^\circ) = \frac{90}{\cdot 86} = 105\quad "\quad "$$

Figure 14. Relationship of Wavelength, Energy, and Lumens

APPENDIX II

The Prisms

This section discusses the means used to minimize the total reflection losses at the surfaces of the prism. We will assume: a) The prism has an equilateral shape, b) In the dispersed beam the separation angle between the red and the blue beam is small compared to the angle of incidence at the prism and c) The incident beam has parallel polarization (i.e. the polarization vector is in the horizontal plane).

Choice of Glass

Prisms are made from various glasses each having different indices of refraction. It is the aim of this section to choose the glass which gives minimum reflection loss. There are no reflection losses when the beam enters and leaves the prism at an angle equal to the Brewster angle. The beam path is shown in Figure 15. We have

$$n = \frac{\sin \theta_1}{\sin \theta_2} = \frac{\sin \theta_4}{\sin \theta_3} \qquad (1)$$

$$\theta_2 + \theta_3 = 60^\circ \qquad (2)$$

$$n = \frac{\sin \theta_1}{\sin(60-\theta_3)}$$

$$\sin \theta_1 = n \sin(60-\theta_3)$$

$$= n(\sin 60 \cos \theta_3 - \cos 60 \sin \theta_3) \qquad (3)$$

if θ_1 and θ_3 are Brewsters angle then

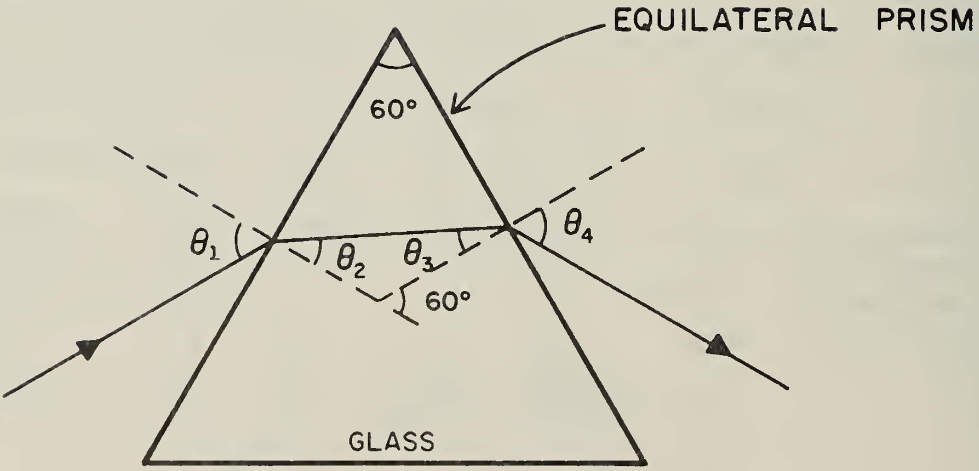


Figure 15. The Path of Beam Through the Prism

$$\tan \theta_1 = n \qquad \sin \theta_1 = \frac{n}{\sqrt{n^2+1}}$$

$$\tan \theta_3 = \frac{1}{n} \qquad \sin \theta_3 = \frac{1}{\sqrt{n^2+1}}$$

$$\cos \theta_3 = \frac{n}{\sqrt{n^2+1}}$$

Substituting these in expression 3 we get

$$\frac{n}{\sqrt{n^2+1}} = n\left[\frac{\sqrt{3}}{2}\,\frac{n}{\sqrt{n^2+1}} - \frac{1}{2}\,\frac{1}{\sqrt{n^2+1}}\right]$$

$$n = \sqrt{3} \simeq 1.73 \qquad (4)$$

Thus the glass having the index of refraction of 1.73 will give no reflection loss in the prism when the angle of incidence (θ_1) and the angle of exit (θ_4) are both equal to Brewsters angle. Thus, the best choice is a prism made from flint glass having n = 1.64.

Losses

Since the index of refraction is not equal to 1.73 the beam entering the prism at Brewsters angle will not leave the prism at the Brewsters angle. This results in losses. The aim of this section is to minimize these reflection losses.

One approach would be to have a prism which is not equilateral but which has the apex angle of the prism (α) made such that the condition of no reflection is achieved. This is achieved when

$$\sin \frac{\alpha}{2} = \frac{1}{\sqrt{n^2+1}} \qquad (5)$$

An another approach would be to use an equilateral prism and tolerate some losses but adjust θ_1 and θ_4 for minimum total loss from calculations it was determined that the total refelction loss is minimum in the region of $53^\circ < \theta_1 < 57^\circ$. Thus $\theta_1 = 55^\circ$ was chosen.

APPENDIX III

In this section we will derive the expression for the arc source output. The schematic of the arc source is shown in Figure 16. The details details, the optics is given in Figure 17. The apertures d and r are iris type diaphrams which can be adjusted for our requirements. We shall make the following assumptions: 1) The arc lamp is isotropic (circular polar plot), 2) The lenses are thin and 3) Negligible reflection losses occur at the lenses.

As noted earlier there is a system limitation on ϕ_3 and d_1.

$$\frac{\text{Light flux captured by lens } L_1}{\text{Light flux emitted by the arc}} = \frac{\frac{\pi}{4} d^2}{4\pi u^2} = \frac{1}{16}\frac{d^2}{u^2}$$

for constant $\phi_2 \rightarrow V = \dfrac{d}{\phi_2}$.

The size of the image of the arc source = $I = s\dfrac{V}{u} = \dfrac{s}{u}\dfrac{u^2}{\phi_2}$ (1)

$$\frac{\text{Light flux transmitted through } r}{\text{Light flux captured by lens } L_1} = \frac{r^2}{I^2} = \frac{r^2}{s^2}\frac{u^2}{d^2}\phi_2^2$$

$$\frac{\text{Light flux transmitted through } r}{\text{Light flux emitted by the arc}} = \frac{1}{16}\frac{d^2}{u^2} \times \frac{r^2}{s^2}\frac{u^2}{d^2}\phi_2^2$$

$$= \frac{1}{16}\left(\frac{r}{s}\right)^2 \phi_2^2$$

The equation shows that I and d are related. If we increase d are related. If we increase d we capture more light but the image I will be large by the same proportion and we lose light at the aperture. The lens L_2 must be kept such that the image of aperture r will be formed on the screen (the final display) which is very distant. In this case the aperture r is kept at the focus of the lens L_2, giving.

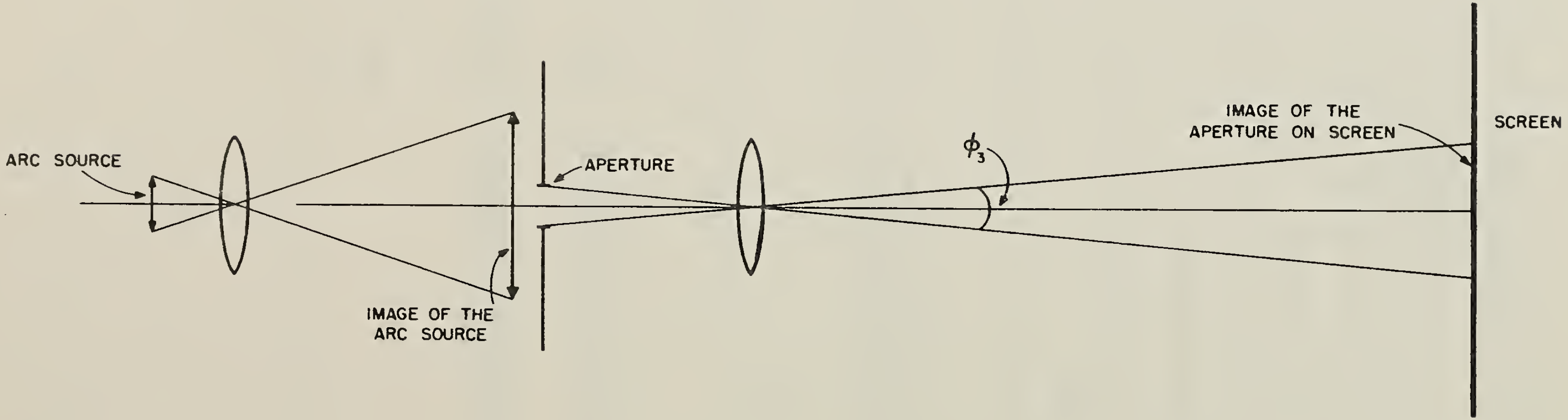


Figure 16. The Arc Source Schematic

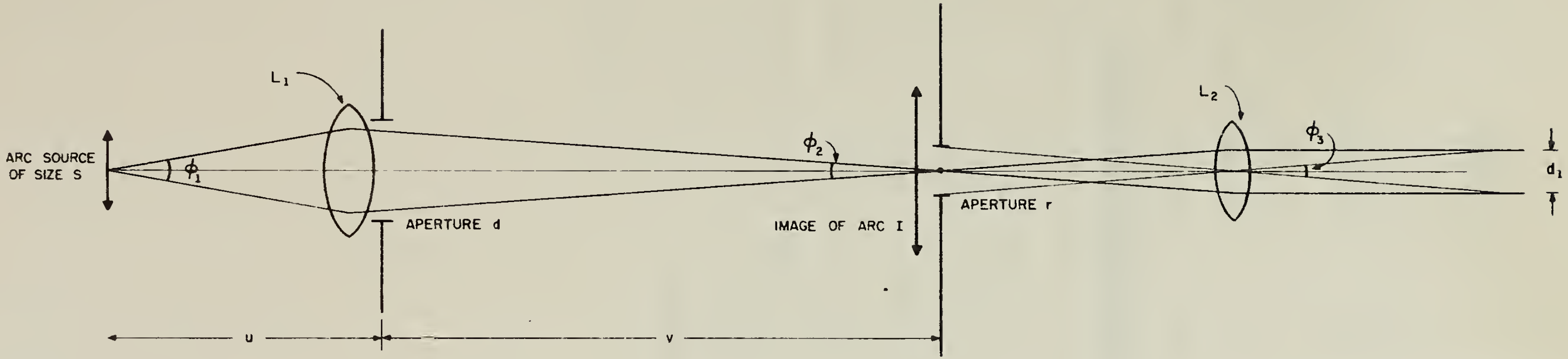


Figure 17. Arc Source Optics

$$\phi_2 = \frac{d_1}{f_2}$$

$$\phi_3 = \frac{r}{f_2}$$

$$\phi_2 = \frac{d_1}{r} \phi_3$$

Then

$$\frac{\text{Light flux transmitted through r}}{\text{Light flux emitted by the arc}} = \frac{1}{16} \frac{d_1^2}{s^2} \phi_3^2$$

VITA

Mehernosh Nariman Cooper was born in Surat, India, on August 31, 1943. He passed his S.S.C. Examination in 1959. He attended M. S. University of Baroda, India, from June 1959 to June 1964. He received his B.E. in Electrical Engineering on June 1964 from the Faculty of Technology, M. S. University of Baroda. He then joined the Indian Institute of Technology, Bombay for his graduate studies, where he received M.Tech. in Electrical Engineering on June 1966.

Mr. Cooper worked as a visiting member in the Tata Institute of Fundamental Research, Bombay, from June 1966 to August 1968. There he worked on the development and design of OLDAP (On Line Data Processor).

In the month of September 1968 he joined the Hardware Systems Research Group of the Department of Computer Science under Professor W. J. Poppelbaum as a graduate research assistant. Since then he has continued to work under Professor W. J. Poppelbaum toward a Ph.D. degree in Electrical Engineering.

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5. Supplementary Notes

6. Abstracts

The Large Screen Color Television System as proposed by Dr. W. J. Poppelbaum is a laser projection display which produces a color television picture on a large screen place some distance away. Constructing an economical display system was the chief objective. Toward this end relatively inexpensive electro-mechanical mirrors are used for beam deflection. These mirrors are synchronized with the composite video.

LASCOT uses a mixed gas (Argon-Krypton) laser as its light source. The blue, green and red colored beams are intensity modulated by electro-optic light modulators (EOLMs). These EOLMs are driven by the blue, green and red picture signals derived from a standard commercial television receiver. These modulated beams are combined by means of dichroic mirrors. This composite beam has a color and hue which depends on the signals at the EOLMs. The composite beam is then deflected horizontally and vertically by means of the horizontal and vertical deflection mirrors. These deflection mirrors are synchronized to their respective synchronization signals which are derived from the television receiver. The picture is projected on a 3 foot by 4 foot high-gain screen. The overall resolution of the picture is in excess of 120 spots horizontally and 100 spots vertically.

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